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COLD STORAGE AND TRANSPORT OF STRAWBERRY PLANTS

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SUMMARY

In laboratory studies no differences were found in rates of cooling of strawberry plants stored in fiberboard cartons or in wood-veneer wirebound crates, both of which contained 1.5-mil polyethylene liners. Simulated shipping tests with cold-stored plants indicated that plants shipped in polyethylene-lined crates during periods of warm temperatures (above 60° F. for a 3-day period) should be refrigerated during transit to prevent objectionable bud and root growth. Commercial storage studies demonstrated the need for proper stacking of packaged plants to obtain good air circulation for best temperature control. This report describes the effect of forced air movement (three air changes per minute) on the cooling rate of strawberry plants packed in three types of containers and stacked in three different patterns. The studies indicated that the concentration of carbon dioxide and oxygen found in film-lined containers of plants handled under various commercial conditions was related to temperature. Concentrations of carbon dioxide as high as 5 percent occurred at 36° but did not affect the appearance of the plants.

Railroad transportation tests with stored and freshly dug plants contained in perforated and nonperforated polyethylene liners showed the marked temperature differences that might be encountered and the resultant damage (mostly excessive plant growth in crown leaf buds, and adventitious root growth) to the plants during transit under adverse conditions.

INTRODUCTION

Commercial cold storage of strawberry plants in the United States is only about 28 years old. Before 1941, strawberry plants were dug in early spring by the grower, or by nurserymen for resale to growers. These plants were generally semidormant, but some were nondormant (active growth), a condition that limited their desirability for planting stock. The short period available to nurserymen for digging and preparing their plants for resale when demand for planting stock was at its peak often resulted in plants of poor quality and poor chance for field survival. In 1938, nurserymen requested the assistance of the USDA, Division of Fruit and Vegetable Crops and Diseases, in initiating storage experiments for strawberry plants. The detailed research of Mark H. Haller of the Division,[1] in conjunction with concerned nurserymen of the Eastern Shore of Maryland, brought about the development of a method of cold-storing strawberry plants from December to April. These studies resulted in the development of a sizable strawberry-plant storage and shipping industry in the United States. In 1969, approximately 200 million plants with an estimated value of from $4 to $6 million are stored annually. The findings of early studies resulted in two methods of storing the plants. In one method, plants "in the rough" (uncleaned) were placed in bushel baskets lined with burlap for temporary storage at 30° to 32° F. In the second method, cleaned and bundled plants were packed in moist sphagnum moss in wirebound or slatted wooden crates, a practice that allowed storage for 1 to 3 months at 30° to 32°.

As the market for stored plants expanded to include sales to home gardeners, with national and international shipments, the necessity for having plants retain a high quality after storage became more important. The expanded markets also required storage for longer periods without loss of plant quality.

In 1955, the U.S. Department of Agriculture, in conjunction with commercial plant growers, developed the use of polyethylene liners for packing bare-rooted plants for storage.[2] This packing method is now used almost universally by commercial strawberry-plant nurserymen because it proved to be not only less expensive and more convenient, but it maintained better plant quality for up to 8 to 10 months, and reduced shipping costs.

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[1] Haller, M. H. WINTER STORAGE OF STRAWBERRY PLANTS. Amer. Nurseryman 77(7): 5–8. 1943.

[2] Worthington, J. T., and Scott, D. H. STRAWBERRY PLANT STORAGE USING POLYETHYLENE LINERS. Amer. Nurseryman 105(9): 13, 56–57. 1957.

However, the use of the nonsealed polyethylene liners for the bare-rooted plants requires better cooling and commodity-temperature control than was needed in the older system of packing.

The high value of stored strawberry plants, $15 to $45 per cubic foot, compared with $4 to $7 for apples, warranted an investigation of improved storage methods aimed at maintaining desired commodity temperature and at maintaining plant quality for extended periods. (Most cold-stored plants are shipped to retailers and growers by parcel post or railway express without refrigeration.) The effect of shipping conditions on subsequent quality of plants was also investigated.

LABORATORY STUDIES

Cooling Rates in Various Containers

Materials and Methods

Sparkle strawberry plants dug in early fall were cleaned, bundled, and packed bare-rooted in 1.5-mil polyethylene liners in standard wirebound wooden crates or in telescoping fiberboard boxes. Both containers had the same capacity (1,500 plants) and dimensions (26 by 14 by 10 inches). Warm plants were placed in an experimental cold-storage room at a temperature of 30° F. ±1.3°, with forced air circulation. An automatic recording potentiometer, with thermocouples inserted in the middle of a bundle of plants in the center of each container, was used to record plant temperatures at hourly intervals. The test containers were not surrounded by buffer containers.

Results

The rate of cooling was almost identical for the two types of containers, as evidenced by the slope of the curves in figure 1. About 7 days were required for the plants in the wirebound crate to cool from 65° to 32° F. However, plants cooled from 65° to below 40° within 24 hours. In general, the plants remained about 1° warmer in the fiberboard cartons than in the wirebound crates.

Simulated Plant Shipments

Materials and Methods

These tests were conducted at the Beltsville, Md., Laboratory under controlled storage temperatures of ±1° F., and relative humidities of 87 to 95 percent. Four wirebound crates lined with 1.5-mil polyethylene film, each of which was used as a container for 1,500 Sparkle plants previously stored at 30° for 4 months, were transferred to separate storages at one of the following temperature: 60°, 70°, 75°, or 85°. The plants stored at each temperature were examined at 1, 2, 3, 4, and 6 days. At each examination during the simulated shipping period, bud growth, rooting, and decay were recorded.

Results

The effects of the various simulated-transit periods and temperatures on bud growth and rooting of cold-stored Sparkle plants are given in table 1. These tests indicate that when the plants are packed in nonsealed, nonperforated polyethylene-lined crates and stored at 30° F. prior to shipment, they can be successfully subjected to transit periods of up to 3 days if transit temperatures are

TABLE 1.—*Condition of Sparkle strawberry plants held in polyethylene-lined crates at four temperature levels during simulated transit*[1]

No. of days held	Condition of plants at—			
	60° F.	70° F.	75° F.	85° F.
1	No growth	No growth	No growth	½ in. growth in buds.
2	No growth	¼ to ½ in. growth in buds	½ to ¾ in. growth in buds	1 in. growth in buds.[2]
3	No growth	½ to ¾ in. growth in buds	1 to 1½ in. growth in buds	2 to 2½ in. growth in buds.
4	½ to 1 in. growth in buds.	2 to 3 in. growth in buds, plus rooting.	2½ to 3½ in. growth in in buds, plus rooting.	3½ to 4 in. growth in buds, plus rooting.
6	1 to 2 in. growth in buds.	3 to 3½ in. growth in buds, plus rooting.	4 to 4½ in. growth in buds, plus rooting.	4 to 5 in. growth in buds, plus rooting.

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[1] Plants were dug January 25, cleaned, bundled, and packed in crates lined with 1.5-mil nonperforated polyethylene with nonsealed overlapping top closures. The crated plants were stored at 30° F. until April 9, then transferred to the above temperatures to simulate various transit temperatures.

[2] Plants with bud growth of 1 inch or longer are considered not salable.

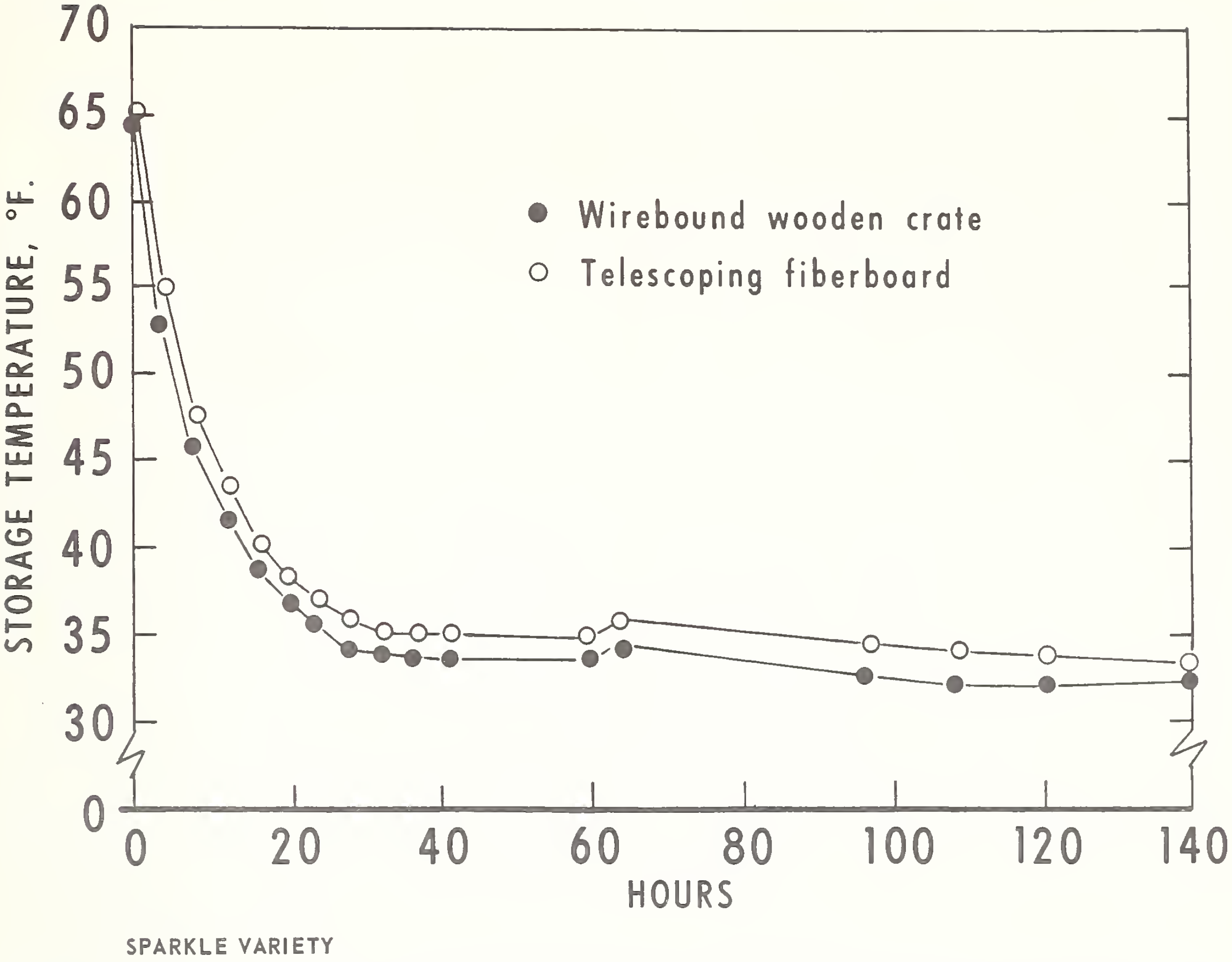

Figure 1.—Cooling rate of Sparkle strawberry plants stored in two types of polyethylene-lined containers at 30° F.

not above 60°. However, 1-day shipments only are advisable if transit temperatures are 70° to 75°. Transit temperatures of 85° would limit shipping time to less than 1 day and are not recommended.

These data suggest that plants shipped in polyethylene-lined crates during periods of warm temperatures (above 60° F. for 3-day periods) should be shipped under refrigeration. Transit temperatures as low as 28° can be used with stored plants.

COMMERCIAL STUDIES

Effects of Stacking Methods on Plant Temperatures

Materials and Methods

The experiment was conducted in commercial storages in Maryland. The work of Ryall and Harvey [3] on grape storage was used as a basis for designing the experiment on refrigeration and stacking. Two commercial cold storage rooms, each containing approximately 7 million plants, were used for these studies. Each room contained 7,000 to 10,000 wirebound crates of strawberry plants of various varieties, packed in 1.5-mil polyethylene liners. In each room, 44 rows of crates were stacked 14 deep and 10 to 12 high.

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[3] Ryall, A. L., and Harvey, J. M. THE COLD STORAGE OF VINIFERA TABLE GRAPES. U.S. Dept. Agr., Agr. Handbk. 159, 46 pp., illus. 1959.

Commodity temperatures at nine positions and air temperatures at three locations were recorded by thermocouples and a potentiometer over a 6-week storage period. The locations of the air thermocouples are shown in table 2. Thermocouples used to record commodity temperatures were placed inside a bundle of strawberry plants packed in the center of each test crate. The test crates were located at front, middle, and rear of room on the load centerline at the following stack positions: Top (next to ceiling), middle (seventh layer from floor), and bottom.

The two rooms were arranged for comparing two test stacking methods: air channels and no air channels. Room 1 had air channels 2 to 3 inches wide between crates and floor, and between stacks of crates. There was also a 12-inch space between walls and stacks, and between the top layer of crates and the ceiling. Wood laths were used in the room with air channels to stabilize the stacks. These laths were placed in each fourth layer of crates and were hold in place by the weight of the crates. Room 2 had no air channels except for a 12-inch space between the top layer of crates and the ceiling. It should be noted that the incoming refrigerated air (delivery air) was different in the two rooms.

Results

Table 2 shows a direct comparison of the commodity temperatures obtained at specified positions in the two test rooms. In the room with no air channels (room 2), the delivery air was 24° F. ±4° throughout storage. This low temperature was necessary so that the delivery air could cool the warmest positions in the room to the desired 30°. However, at the same time that the warm positions were being cooled, plants immediately exposed to the 24° delivery air were subjected to excessively low temperatures. (Strawberry plants freeze at 29° F. ±0.8°.) In contrast, the room with air channels (room 1) was afforded more rapid and uniform cooling with less refrigeration (29° F. ±3°) being required to cool all positions to the desired 30°, and no plants were subjected to excessively low temperatures. If the plants had been warm at the beginning of the tests, cooling would probably have been considerably faster in the room with air channels.

The small amount of extra labor and space required to leave desirable air channels would be offset by the saving in refrigeration cost alone. The main advantage of proper stacking with air channels is that better plant quality can be maintained by proper control of plant temperature during storage.

Effects of Forced Air Circulation on Cooling Rates of Plants in Different Containers

The previous study showed that air channels are desirable for proper cooling and uniform plant temperatures. This study was conducted to determine the effects of forced air circulation and stacking methods on plants stored in three types of containers.

Materials and Methods

In testing, 720 containers of 1,500- to 2,000-plant capacity were used. Plants of the Catskill variety were dug and cleaned over a 1-week period for use in this experiment. The test containers were divided into 360 standard wirebound crates, 180 full-telescope fiberboard cartons, and 180 wax-impregnated corrugated cartons. Twice as many wirebound crates were used than either type of carton because the supply of both fiberboard and wax-impregnated cartons was limited. All containers were the same size and had the same capacity, and all were lined with 1.5-mil polyethylene bags.

The experimental cold storage room used was approximately 12 feet wide, 14 feet high, and 16 feet long. A brine refrigeration system with a bank of six 3-inch-diameter coils was the refrigerating source. A plywood bulkhead was erected approximately 18 inches in front of the coils. Two three-propeller, 18-inch fans were used, each rated at 3,720 cubic feet per minute in free air. Both fans were mounted 4 feet apart with fan openings 6 inches from the ceiling of the room. The fans were powered by one-fifth hp. motors, operated continuously. This arrangement afforded approximately three air changes a minute in the experimental storage area. At the base of the bulkhead was a 6-inch-high opening for returning the air to the cooling unit (fig. 2).

Inside the test room, the ceiling joists were covered with canvas to reduce air eddies. Racks made of wood two-by-fours spaced equidistantly along the floor in the same direction as the airflow provided a stacking base with a 2-inch airspace between the floor and the bottom layers of containers. The airspace between bulkhead and walls and the containers was 12 inches, and between ceiling and containers, 24 inches. Finally, five air channels running parallel to the bulkhead provided 3 inches of airspace between designated stacking patterns. In stacking, the longest surfaces of the containers were placed parallel to the bulkhead and the five interior air channels.

The following stacking patterns (from the bulkhead back) were used: Triple stacks of wax-

TABLE 2.—*Temperatures of crated strawberry plants stacked with and without air channels in two commercial cold storage rooms*[1]

Position of thermocouple	Temperature in room 1 [2] (crates stacked with air channels) after—						Temperature in room 2 [2] (crates stacked without air channels) after—					
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks
	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
Rear of room:												
Top layer	31.0	30.1	30.4	30.6	30.9	30.5	30.8	31.8	33.9	28.8	29.6	27.8
Middle layer	29.5	29.0	29.6	29.3	29.9	29.1	32.8	33.9	36.0	30.7	30.5	29.6
Bottom layer	30.6	30.5	31.0	31.0	30.4	30.5	32.3	32.5	36.0	30.0	30.4	28.5
Air, middle layer between crates	29.5	29.9	28.5	28.3	28.5	28.0	[3] 31.7	[3] 31.3	[3] 34.0	[3] 28.8	[3] 27.7	[3] 27.7
Middle of room:												
Top layer	32.7	30.9	30.3	30.1	31.2	29.3	29.8	30.7	31.8	27.7	25.3	26.0
Middle layer	30.8	31.1	29.9	30.8	30.5	29.0	31.5	32.4	34.4	28.6	28.1	28.1
Bottom layer	31.0	31.5	30.1	30.1	30.0	30.0	28.9	29.8	32.4	27.3	27.3	26.7
Air, top layer between crates	28.7	27.0	27.5	28.5	28.2	26.0	[3] 30.5	[3] 30.7	[3] 34.3	[3] 27.5	[3] 26.6	[3] 27.5
Front of room:												
Top layer	32.3	31.8	31.5	32.2	30.0	32.0	27.8	27.6	28.7	24.2	23.7	24.7
Middle layer	29.6	29.2	29.0	29.5	29.0	29.0	33.2	33.9	35.1	28.9	29.1	27.9
Bottom layer	32.3	31.3	30.3	30.3	30.1	30.0	30.5	31.1	35.8	30.8	30.7	29.3
Air, bottom layer between crates	30.5	30.5	29.8	30.5	29.5	29.7	[3] 27.9	[3] 30.8	[3] 30.0	[3] 25.7	[3] 25.3	[3] 26.0
Average temperature:												
Top layer	32.0	30.9	30.7	30.9	30.7	30.6	29.5	30.0	31.5	26.9	26.2	26.2
Middle layer	29.9	29.8	29.5	29.9	29.8	29.0	32.5	33.4	35.2	29.4	29.2	28.5
Bottom layer	31.3	31.1	30.5	30.5	39.2	30.2	30.6	31.1	34.7	29.4	29.5	28.2

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[1] Plants in test room 1 were held at 29° F.±3°; plants in test room 2 were held at 24° F.±3°.

[2] Room 1 had 2- to 3-inch air channels between crates and floor and between stacks of crates, and a 12-inch space between stacks and walls. Both rooms had 12-inch spaces between top layers of crates and ceilings.

[3] Temperature taken at middle layer.

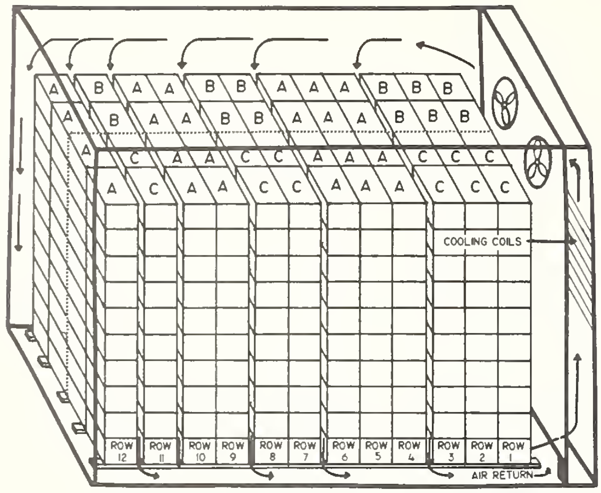

Figure 2.—Schematic diagram of experimental storage room designed for determining cooling rates of strawberry plants stored in three stacking patterns. Three types of containers were used: *A*, Wood wirebound crates; *B*, fiberboard boxes; and *C*, wax-impregnated fiberboard boxes. Temperatures were determined in various containers along the load centerline (dashed line).

impregnated and fiberboard telescope cartons (rows 1, 2, and 3); air channel; triple stacks of wirebound crates (rows 4, 5, and 6); air channel; double stacks of wirebound crates (rows 9 and 10); air channel; single stacks of wax-impregnated and fiberboard cartons (row 11); air channel; and single stacks of wirebound crates (row 12).

The experimental patterns of stacks and airspaces was such that each surface of an individual container, or corresponding surfaces of neighboring containers, did not necessarily receive the same exposure to circulating air. With the triple stacks, only those containers with outwardfacing surfaces were exposed to the forced air circulation. None of the inner containers in the middle stack (row 2) had surfaces facing on airspace. Each container in the double stacks, however, had one to three surfaces exposed to airspace, and all of the containers in the single stacks had two to four exposed surfaces.

Thermocouples were placed inside bundles of plants packed in the centers of containers in the top, middle, and bottom layers of each stacking pattern. Each type of container in each stacking pattern was included in testing. All containers provided with thermocouples were selected from the crates or cartons stacked along the load centerline. An automatic recording potentiometer was used to record temperatures at 2-hour intervals throughout the 36-day test period. The initial plant temperatures at the start of test ranged from 45° to 65° F. These temperature differences were caused by the large number of plants required for the test, which took approximately 1 week to prepare. Thus, some plants were placed in cold storage before others. To reduce the effect of this initial temperature difference, the half-cooling-rate formula used by Guillou[4] and by Stewart and Lipton[5] was applied to data. The "half-cooling time" is the time required to reduce the temperature difference (commodity temperature minus the coolant temperature) by one-half. Theoretically, this rate is independent of the initial temperature and remains constant throughout the cooling period.

Results

The cooling rates obtained show that with forced air (three air changes per minute) and delivery air of 30° ±1.5° F., plants could be cooled from an average initial temperature of 53° to 31° within 14 days at all test positions. The cooling rates of the plants in wirebound crates were slightly more rapid than the crates of plants in the two types of cartons (fig. 3). Plants in single-stacked rows cooled more rapidly and to a slightly lower temperature than plants in the double- or triple-stacked rows of containers (fig. 4 and table 3).

The lack of uniform initial temperatures between test packages, discussed earlier, caused a need for the data to be analyzed in terms of half-cooling time. The mean half-cooling time required was least for the wirebound crates and highest for the wax-impregnated fiberboard cartons (table 4). The data indicate that plants in triple stacks of the wax-impregnated fiberboard and the fiberboard telescoping cartons required less hours to cool than plants in double stacks of similar containers. It is believed that the placement of the stacks caused this result: the triple stacks were closer to the cold-air supply in this test (fig. 2). The data also show that the middle position in the stack is the most difficult to cool, as would be expected.

The physical condition of the plants was excellent when they were removed from storage. Even when relatively high-velocity air movement was used for 36 days, no visible moisture loss was observed. The polyethylene liners used within all types of containers afforded excellent protection against desiccation.

The data suggest that forced air circulation would be desirable for precooling because plants within polyethylene liners are cooled relatively

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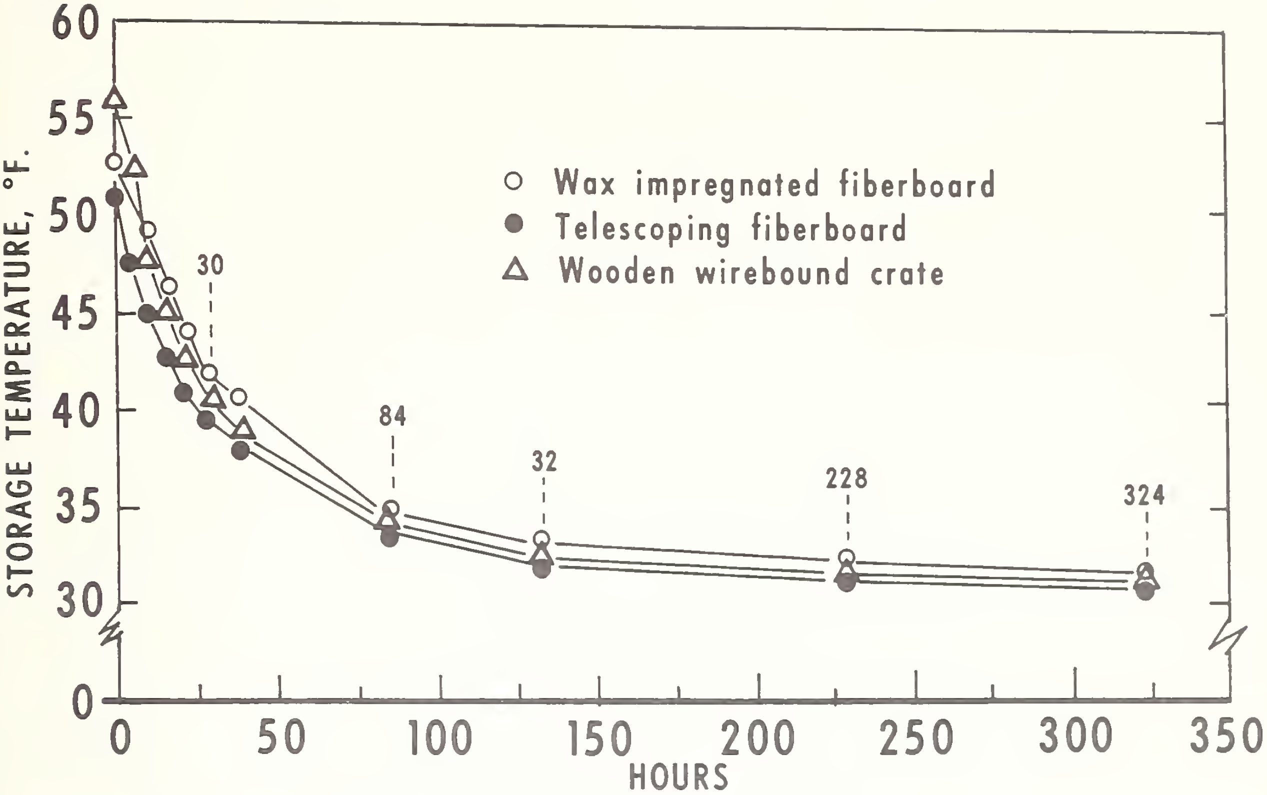
[4] Guillou, Rene. COOLERS FOR FRUITS AND VEGETABLES. Calif. Agr. Expt. Sta. Bul. 773, 66 pp., illus. 1960.

[5] Stewart, J. K., and Lipton, W. J. FACTORS INFLUENCING HEAT LOSS IN CANTALOUP DURING HYDROCOOLING. U.S. Dept. Agr. Market. Res. Rpt. 421, 12 pp. 1960.



CATSKILL VARIETY PACKED IN POLYETHYLENE LINERS
EACH POINT THE MEAN OF NINE POSITIONS (3 STACKING METHODS, 3 LOCATIONS IN STACKS)

Figure 3.—Effect of forced air movement on cooling rate of Catskill strawberry plants stored at 30° F. in three types of containers.

slowly. The use of a portable precooling system could do the required cooling very effectively within a commercial 30° F. storage room. This precooling system would save double handling. The precooling should be done periodically as the room is being filled with small units of plants throughout the season, such as the units used in these studies. Perhaps a sliding baffle board on permanent slide tracks with fans mounted in the baffle and portable canvas drop curtains at the sides could precool effectively and inexpensively.

Effects of Various Packaging Methods on Crated Plants

Materials and Methods

Sixty-six thousand strawberry plants of various varieties were used in this study. The plants were selected at random from three commercial nursery lots. Five packaging methods were compared, as follows: (1) the standard wirebound crate (26 by 14 by 10 inches) packed with moist sphagnum moss on top, bottom, sides, and between layers of plant bundles; (2) the wirebound crate packed with a 2-mil (0.002 inch) polyethylene liner 30 inches long and 36 inches wide; (3) the wirebound crate packed as in method (2) except that three layers of moist sphagnum moss were included; (4) the wirebound crate packed as in method (2), except that one layer of moist sphagnum moss was placed inside at the bottom of the liner; and (5) the wirebound crate packed with 2-mil polyethylene sheeting inserted and light layers of sphagnum moss placed at the bottom and between the layers of plants. The liners used in methods (1), (2), (3), and (4) were not perforated and were not sealed; their tops were closed by being overlapped after the crates were packed. The ends of the sheeting used in method (5) were left open.

These packages were stored with other commercially stored plants in three commercial cold storages. The storage rooms operated at approximately 30° F. throughout an 8- to 10-month storage period.

All test packages were removed from storage in September for inspection. Thus, the storage period ranged between 8 and 10 months. Criteria for the

TABLE 3.—*Effect of stacking patterns and types of containers on cooling rates of dormant Catskill strawberry plants exposed to forced air movement*

Container, stacking pattern, air temperature, and coil temperature	Initial temperature	Temperature in center of container after[1]—			
		12 hr.	36 hr.	84 hr.	324 hr.
	° F.	° F.	° F.	° F.	° F.
Fiberboard Telescope Carton:					
Single-row stacking	52.4	44.8	36.9	32.2	30.3
Double-row stacking	50.1	45.2	39.2	35.2	31.6
Triple-row stacking	49.4	44.1	37.2	32.6	29.6
Wirebound Crate:					
Single-row stacking	56.5	46.6	35.8	31.6	30.7
Double-row stacking	62.8	52.2	40.6	34.4	30.3
Triple-row stacking	50.2	45.3	37.7	35.2	31.4
Wax-Impregnated Fiberboard Carton:					
Single-row stacking	51.8	47.8	39.2	33.7	30.0
Double-row stacking	49.3	47.2	40.8	35.7	31.5
Triple-row stacking	56.0	50.5	40.8	34.2	31.3
Air Temperatures:					
8 in. from floor, rear of room	42.0	37.0	32.7	31.0	30.0
8 in. from floor, front of room (air return)	32.0	30.5	29.6	28.9	28.5
8 in. from ceiling, one-half length of room	32.3	30.8	30.2	30.0	28.9
8 in. from ceiling, rear of room	32.3	30.8	30.2	30.0	29.0
Coil Temperatures	2.0	4.5	4.9	4.0	4.0

[1] Temperatures given are the average temperature of the ceiling, middle, and floor layers in each stacking pattern.

appearance classification—poor, fair, good, and decayed—were based on color and turgidity of, and amount of decay in, leaves and roots. "Poor" indicated dry roots and dead leaves. "Fair" indicated noticeably dry plants with leaves slightly wilted but salable. "Good" indicated moist, turgid roots and green, turgid leaves. "Decayed" indicated that mycelium was visible and decomposition advanced enough in plant leaves to render the plants nonsalable.

To observe field response, 7,700 plants from three of the five types of packages were planted as follows: 2,700 at Salisbury, Md., and 5,000 at Coastal Plains Research Station, Willard, N.C. Before the Salisbury planting, the experimental plants were held for 2 days at 65° F. after they were removed from storage. The other plants were shipped by express to Willard for immediate planting. Survival and vigor of the plants were observed approximately 1 month after planting.

Results

Plants stored in crates with full polyethylene liners or with sheets of polyethylene, with or without sphagnum moss, were superior in leaf and root appearance to plants stored in moss in the standard wirebound crates without polyethylene liners or sheets.

Plants stored bare-rooted in polyethylene-lined crates without moss rated as high as plants stored in polyethylene with moss. No decay was found in the plants stored in polyethylene without moss. However, decay was found in the plants stored in crates with moss in four layers of the package, and in plants stored in polyethylene liners with three layers of moss (table 5).

Decay was found primarily in plants of one variety, but the total decay for all varieties was less than 6 percent in plants packed in the two types of packages that had decay. Excessive moisture found in the bottom layer of moss in certain test packages probably contributed to the high decay development. The decay, mostly *Botrytis cinerea*, was generally found on leaves and roots; none was found in crown tissue.

Plants stored in polyethylene liners, with or without moss, had green, turgid leaves and bright, succulent roots. In comparison, leaves of plants in the standard wirebound crates with moss but without polyethylene liners were yellow to brown, and were generally dry and appeared dead. The moss in these crates was dry in the top and bottom layers and at the ends of the crates. Some plant roots in these locations were dry and severely desiccated. Further, the field response was better from the polyethylene-packed plants than from plants packed in standard crates with moss but without polyethylene (table 5).

The results of these tests have been substantiated by the continued success of three cooperating nurserymen, who have used polyethylene liners for storing approximately 50 million plants per year.

The cost of packing with film liners but without moss is approximately 10 cents per crate less than the cost of packing a standard wirebound crate with moss. Advantages of the polyethylene-liner

TABLE 4.—*Half-cooling time of dormant Catskill strawberry plants stored at 30° F. in three types of containers arranged in different stacking patterns, and exposed to forced air movement*

Type of container and stacking pattern[1]	Half-cooling time			
	Floor layer	Middle layer	Ceiling layer	Mean, all layers
	Hours	*Hours*	*Hours*	*Hours*
Wirebound crate:				
Single stack	14	20	20	18
Double stack	18	40	11	23
Triple stack	26	40	29	32
Mean	19	33	20	24
Fiberboard telescope carton:				
Single stack	14	34	19	23
Double stack	26	41	30	33
Triple stack	36	36	12	28
Mean	28	37	20	28
Wax-impregnated fiberboard carton:				
Single stack	20	30	30	26
Double stack	37	46	44	42
Triple stack	32	40	22	30
Mean	30	39	32	33

[1] All containers had polyethylene liners with overlapped top closures.

method of packing are: reduced materials cost, lighter packages, better humidity within packages, and ease of removing plants from the containers.

Certain precautions should be taken in using this method of packing. Plants should be free of soil and not excessively moist, and they should be placed in 30° F. cold storage immediately after being packed. Precooling is also highly desirable.

Carbon Dioxide and Oxygen Concentrations in Commercially Stored, Polyethylene-Packed, Crates of Plants

Materials and Methods

Fifteen varieties of strawberry plants packed in 1.5-mil polyethylene-lined wirebound crates and stored at 30° F. in two commercial storages were sampled three times for carbon dioxide (CO_2) and oxygen (O_2) concentrations. Each container held 1,500 to 2,000 dormant plants and each weighed approximately 40 pounds. The polyethylene liners were not perforated and the tops of the liners were overlapped and left unsealed. Carbon dioxide was analyzed with a portable Burrell Kwik-Check gas analyzer and O_2 with a portable Beckman O_2 analyzer. The instrument for measuring CO_2 was specified as accurate to 0.25 percent and the O_2 analyzer to 0.50 percent. Temperature measurements were made at the same time as gas measurements from a similar position inside the liner.

Results

The CO_2 level during storage ranged from 0 to 5.5 percent and the O_2 level from 15 to 20.8 percent (table 6). The appearance of the plants was similar for the various levels of CO_2 and O_2 found. The percentage of CO_2 that accumulated was affected by storage temperature. Film liners for plants held at 30° F. (recommended commodity temperature for storage) had no measurable CO_2 accumulation and a mean of 20.4 percent O_2. Plants with the higher temperatures had slightly higher CO_2 percentages and lower O_2 percentages.

No effect on mold development was noted between high or low levels of CO_2 between liners. The data indicate that overlapped closures of the film liners provide adequate ventilation for plants held at recommended low temperatures.

Transportation Tests With Stored and Freshly Dug Strawberry Plants

A high percentage of commercially handled cold-stored strawberry plants are eventually shipped each year by parcel post or railway express. Periodic complaints of poor plant condition have been reported at destination by the receivers.

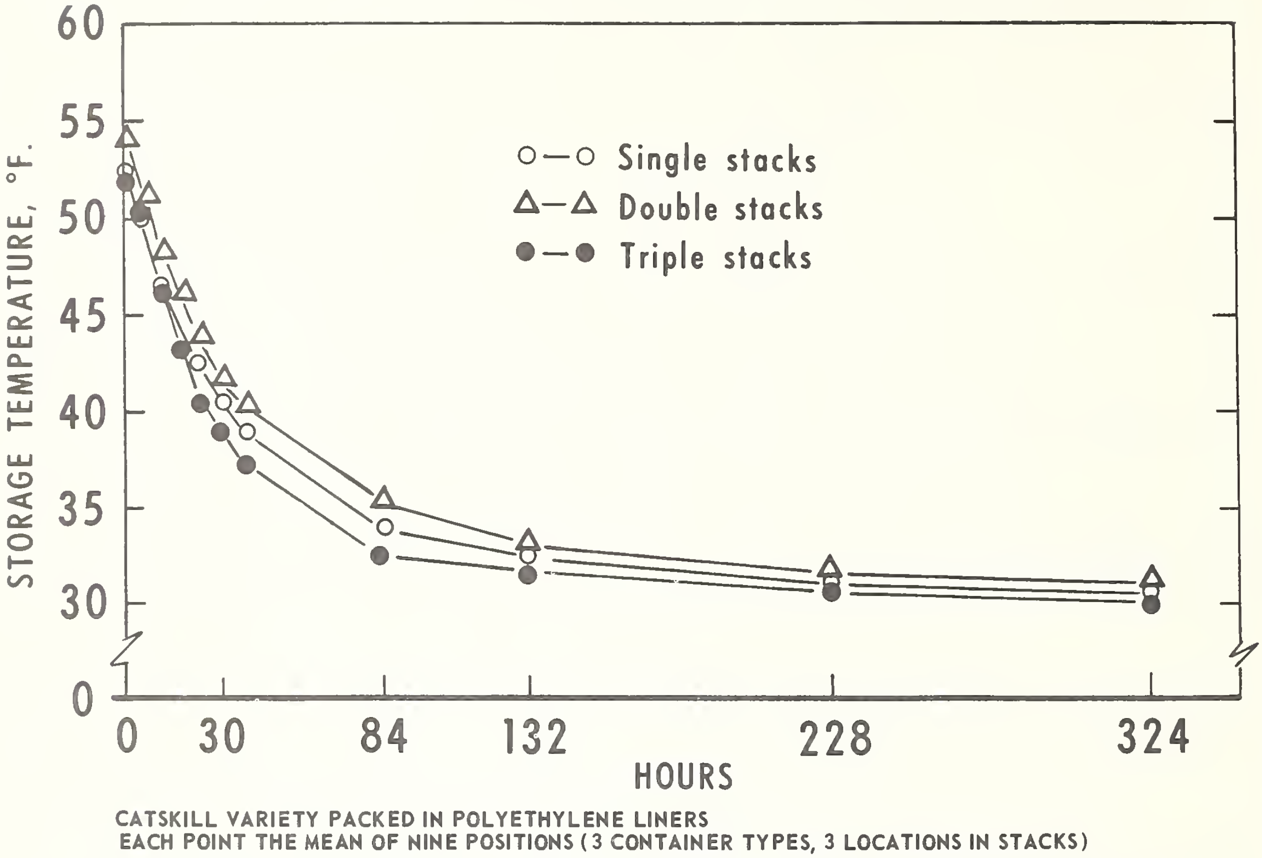


FIGURE 4.—Effect of forced air movement on cooling rate of Catskill strawberry plants stored at 30° F. in three stacking patterns.

No information was available on transit temperatures of strawberry plants, particularly when the plants were shipped in polyethylene liners. The object of these studies was first to obtain information on actual temperatures during shipment and on plant condition, then to analyze the results to find where, when, and why deterioration occurred and to recommend improved handling procedures.

Materials and Methods

Two express rail shipments were made in late April and early May from Beltsville, Md., to the Horticultural Field Station at Miami, Fla. No special treatment was given to the nonrefrigerated test packages during shipment. Plants were obtained from commercial nurserymen located in Maryland and Delaware. Cold-stored Missionary plants were used in the first test; cold-stored and freshly dug Sparkle plants were used in the second test. The stored plants were dug in January and stored at 30° F. until shipped. The freshly dug plants were dug 3 days before shipment and were held at 40° to 50° until shipped.

The standard wirebound crate containing 1,500 to 2,000 plants was used for the shipping package. Three methods of packing were compared: (1) wirebound crates with moist sphagnum moss packed around the roots of the plants on the top and bottom layer; (2) wirebound crates with 1.5-mil nonperforated polyethylene liners with no moss and overlapped top closure; and (3) same as (2) except that the polyethylene liners had twenty ½-inch-diameter holes dispersed over the surfaces for added ventilation.

Plant temperatures were recorded by recording thermometers placed in the centers of test packages. Air temperature was recorded by similar thermometers fastened to the outsides of the packages. A portable Orsat gas analyzer was used to measure the percentage of carbon dioxide and oxygen in the test packages on their arrival in Florida.

Results

In the first shipment, cold-stored plants were in transit from Maryland to Miami for 4 days.

The transit temperatures during rail shipment are given in figure 5. The air temperature reached a high of 81° F., and averaged about 70°. The average plant temperature for all types of containers for the 4-day period was 57°. Plant temperatures were similar, except that during the first 36 hours the temperature in the unlined crates with moss was 41° and the temperature in the polyethylene-lined crates was 47°. This difference may have been caused by the cooling potential of the cold moss, which was not included in the polyethylene-lined crate. Also, the temperature remained slightly lower in the perforated polyethylene-lined crates than in the nonperforated polyethylene-lined crates.

At arrival in Miami after the 4-day transit period, all plants were in good condition, with no mold present. Leaves of plants in the nonperforated liners appeared fresher than leaves of plants in the other two types of packages. Plants in both types of film-lined packages appeared fresher than plants packed in moss in the unlined crate. Some root growth was noted on plants in all packages, with slightly less on those in moss-packed crates.

The results of a second rail transportation test to Florida are shown in figures 6 and 7. These graphs show the slightly lower transit temperature in both freshly dug and stored plants when the polyethylene liners were perforated. When both freshly dug plants and plants from cold storage were shipped in crates with nonperforated liners, comparisons indicated that both rose in temperature to about the same extent during transit. The average plant temperature during transit for all packing methods was 72° F. for the stored plants and 69° for the freshly dug plants. When the plants were examined in Florida after 4 days in transit, the CO_2 and O_2 percentages within the liners were as follows: freshly dug plants in perforated liners, 0 percent CO_2, and 16.2 percent O_2; freshly dug plants in nonperforated liners, 4 percent CO_2, and 12.8 percent O_2; and stored plants in nonperforated liners, 3.8 percent CO_2, and 14.2 percent O_2. Upon arrival, plants under all treatments had a slight amount of root growth and excessive top growth. Excessive top growth is undesirable, and would probably affect field survival.

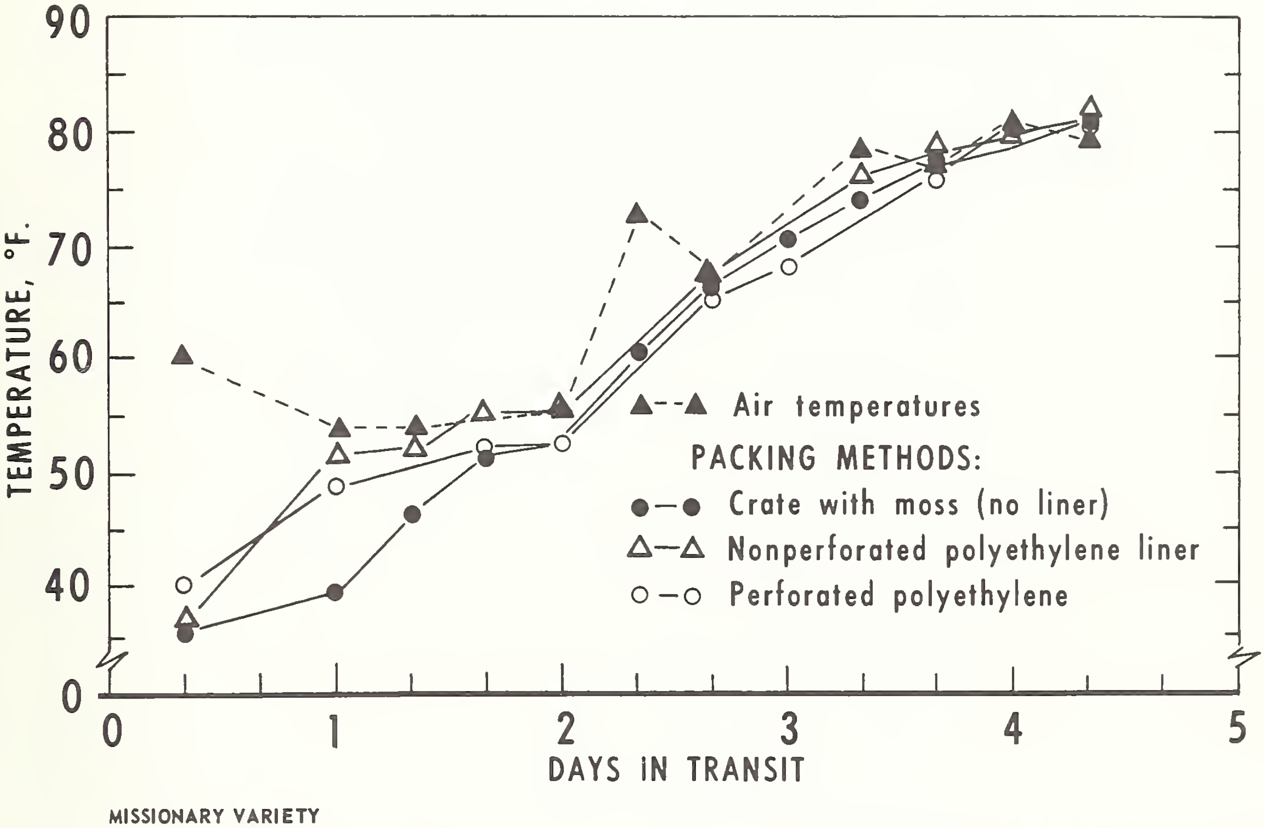


Figure 5.—Effect of three packing methods on commodity and air temperatures of cold-stored Missionary strawberry plants during rail transport.

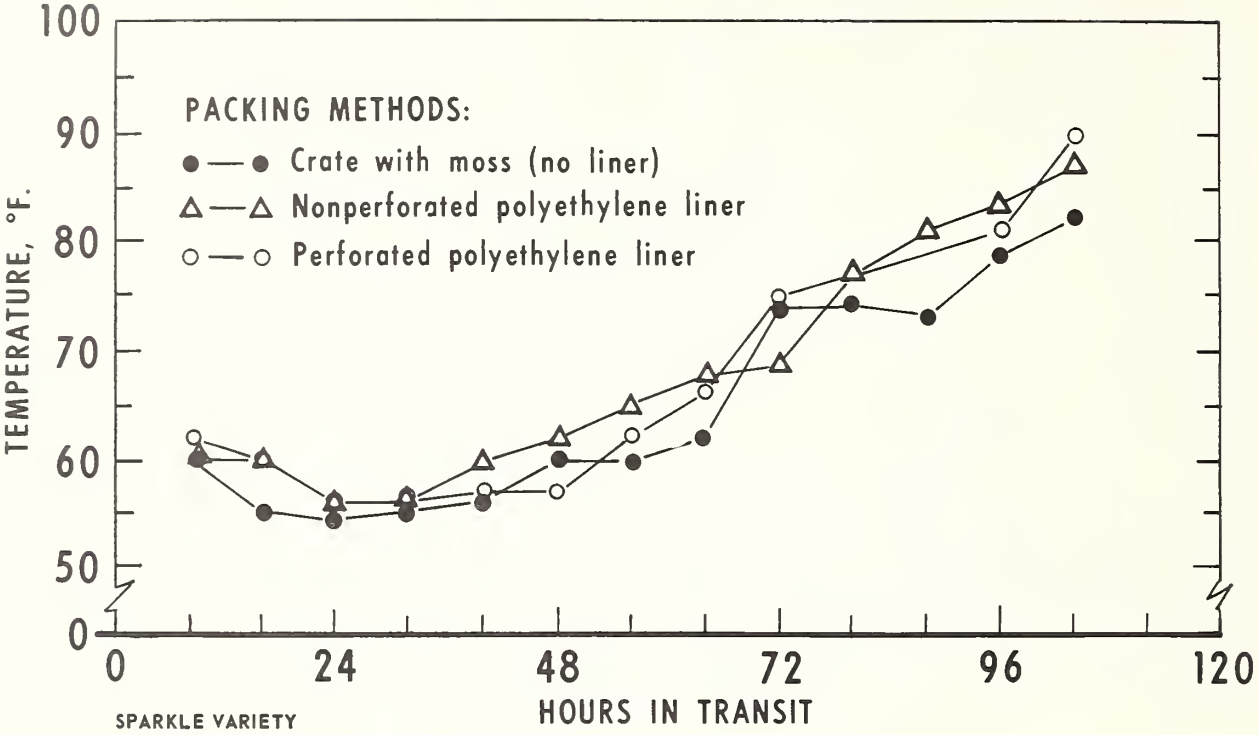


FIGURE 6.—Effect of three packing methods on commodity temperatures of cold-stored Sparkle strawberry plants during rail transport.

TABLE 5.—*Appearance and field response of variously packaged strawberry plants after 8- to 10-months storage at 30° F. under commercial conditions*

Packing methods [1]	Number of plants tested [2]	Appearance of plants after storage [3]				Field response of Maryland planting [4]		Field response of North Carolina planting [4]	
		Decayed	Poor	Fair	Good	Plants surviving	Vigorous plants	Plants surviving	Vigorous plants
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No polyethylene liner, four layers of moss	19,425	8	29	57	6	72	46	74	27
Polyethylene liner, no moss	14,550	0	0	0	100	87	74	93	58
Polyethylene liner, moss bottom layer only	9,875	0	0	0	100				
Polyethylene liner, three layers of moss	18,350	4	2	0	94	81	67	92	41
Polyethylene sheet with two open ends, three layers of moss	4,200	0	0	0	100				

[1] All test plants were stored in standard wood wirebound crates, each holding 1,400 to 1,500 plants. All polyethylene liners used were 2-mil thick; liners' tops were closed and overlapped but were not sealed. For tests requiring moss packing, premoistened sphagnum moss was used.

[2] Plants tested included many varieties, all from one of three originating nurseries. Plants were stored in one of 3 commercial storages.

[3] Criteria used to classify plants by appearance were: "Decayed"=mycelium visible and decomposition advanced enough to render plants nonsalable; "Poor"=dry roots, dead leaves; "Fair"=noticeably dry plants, leaves slighted wilted but salable; "Good"=moist, turgid roots and green, turgid leaves.

[4] Plantings were at Salisbury, Md., and Willard, N.C. Figures for "Vigorous plants" are percentages of total number of plants used for each planting.

TABLE 6.—*Plant temperatures and concentrations of carbon dioxide and oxygen in polyethylene-lined crates of dormant strawberry plants stored at 30° F.*[1]

Date analyzed and nursery [2]	Variety	Date packed and stored	Commodity temperature	Carbon dioxide	Oxygen
			°F	*Percent*	*Percent*
January 31:					
A	Pocahontas	Dec. 20	32	1. 3	20. 8
A	Empire	Dec. 28	31	2. 5	18. 9
A	Florida 90	Jan. 3	32	2. 5	18. 5
A	Superfection	Jan. 11	33	3. 8	17. 6
A	Streamliner	Jan. 2	32	1. 3	20. 2
A	Missionary	Jan. 28	32	4. 1	15. 4
B	Premier	Dec. 19	32	2. 5	18. 7
B	Dixieland	Jan. 1	32	1. 0	20. 7
B	Pocahontas	Jan. 14	32	1. 5	20. 5
B	Premier	Jan. 20	33	4. 5	16. 0
B	Premier	Dec. 19	36	5. 5	15. 0
February 27:					
A	Pocahontas	Dec. 20	33	1. 4	20. 0
A	Empire	Dec. 28	30	0	20. 6
A	Florida 90	Jan. 8	34	1. 3	19. 3
A	Superfection	Jan. 11	31	1. 7	19. 2
A	Streamliner	Jan. 2	30	0	20. 0
B	Premier	Dec. 19	33	1. 3	19. 8
B	Dixieland	Dec. 19	33	0	20. 6
B	Pocahontas	Jan. 14	33	1. 3	19. 5
B	Catskill	Feb. 1	31	2. 9	17. 9
B	Robinson	Feb. 1	31	1. 7	19. 4
March 26:					
A	Big Joe	Jan. 8	31	2. 1	19. 6
A	Red Star	Feb. 19	31	1. 1	20. 5
A	Surecrop	Mar. 12	31	1. 3	20. 5
A	Dunlap	Dec. 27	31	2. 0	19. 5
A	Mastodon	Dec. 26	31	1. 2	20. 1

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[1] O_2 measurements obtained with portable O_2 analyzer, CO_2 measurements with Burrell Kwik-Check Gas Analyzer. The temperatures and gas measurements were made at random from different crates throughout the storage room. Measurements were made near the top of the crate through the plastic liner without disturbing the plants.

[2] The 15 varieties of plants tested were held in two commercial storages, designated "A" and "B" in this table.

GENERAL RECOMMENDATIONS

The results of these tests demonstrate that to maintain high-quality plants during storage and shipment, strawberry growers and handlers should adhere to the following recommendations: high quality, dormant, and properly cleaned and bundled plants should be used. They should be packed in 1.5 mil polyethylene liners with the tops overlapped but not sealed, and without moss. The standard wood-veneer wirebound crates or fiberboard containers, both with polyethylene inserts, have been found satisfactory for storing strawberry plants. The plants should be cooled within 3 days to 30° F., then transferred to regular cold storage (30°).

To maintain uniform low temperatures, airspaces should occur between at least every second row of crates, between walls and crates, and between ceiling and crates. The crates should be stacked on floor racks to provide airspaces under the bottom crates. A distance of 2 to 4 inches will provide enough space for air to circulate. Wood lath or other material should be placed within stacks of crates to prevent shifting stacks from closing the air channels. The largest surface areas of the crates should face the air channels. Fans with enough capacity to move the refrigerated air uniformly through the air channels should be installed. During storage, the plant temperatures inside the liners should be 30° F. and fluctuating temperatures should be avoided.

Packages should be shipped immediately after removal from storage to take advantage of the

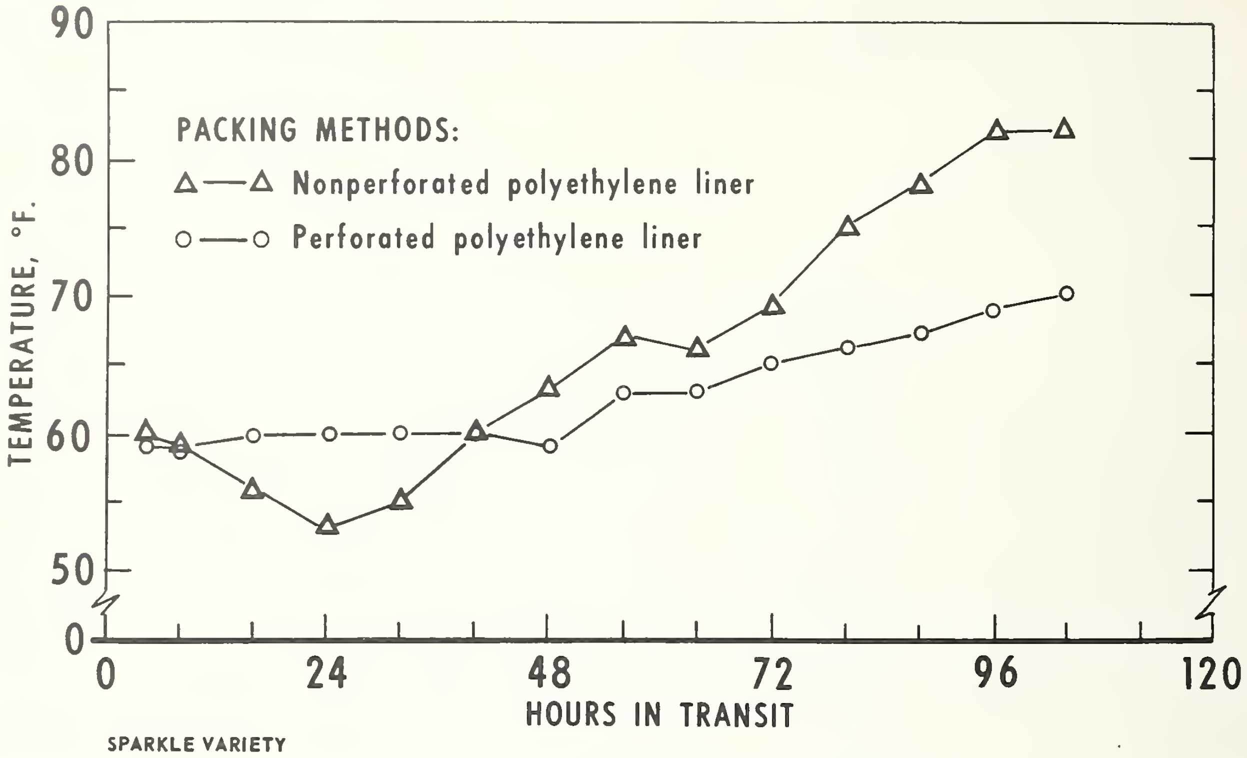

FIGURE 7.—Effect of three packing methods on commodity temperatures of freshly dug Sparkle strawberry plants packed in perforated and nonperforated polyethylene-lined crates during rail transport.

existing low temperatures in the package. The liners should be perforated before shipment to reduce carbon dioxide and heat buildup during transit. Refrigerated transit at temperatures as near 30° F. as possible is recommended. Plants should not be exposed to temperatures below 28°. For unrefrigerated shipments, the data given in table 1 can be used as a feasibility guide.

Other literature especially helpful to cold storage operators are the reports prepared by Ryall and Harvey[6] and by Guillou,[7] which deal with the many engineering aspects of cooling and cold storage.

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[6] See footnote 3, p. 3.

[7] See footnote 4, p. 6.

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